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INNOVATIVE TECHNIQUES TO PREDICT ATMOSPHERIC EFFECTS ON SENSOR PERFORMANCE

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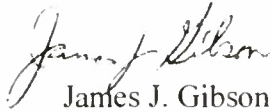Chestnut Hill, MA 02467

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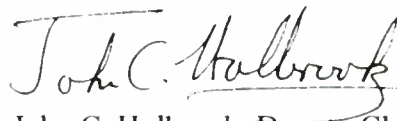
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14. ABSTRACT

The Boston College Institute for Scientific Research is conducting innovative research in areas relating to development and demonstration of new technologies to predict atmospheric effects on sensor performance for acquisition, mission planning and employment to the Air Force's current and next generation electro-optical (EO) systems. Emphasis includes space-, air-, and ground-based EO systems, laser systems including the Airborne Laser (ABL), surveillance and lidar and radar remote sensing technologies.

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And Forecasting

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1.   EXECUTIVE SUMMARY

During the period September 2008 through September 2009, we conducted innovative research in areas relating to development and demonstration of new technologies to predict atmospheric effects on sensor performance for acquisition, mission planning and employment of the Air Force's current and next generation electro-optical (EO) systems. Emphasis includes space-, air-, and ground-based EO systems, laser systems including the Airborne Laser (ABL), surveillance and lidar and radar remote sensing technologies.

The work summarized above resulted in presentations, technology-related conferences attended and coordination with technology related organizations.

2.   TURBULENCE EFFORTS

Boston College, in support of the Turbulence Effort, coordinated with Atmospheric and Environmental Research, Inc (AER) on FY08 Cloud Optical Properties, and with the National Center for Atmospheric Research (NCAR) on assimilation of the Weather Research and Forecast (WRF) data. Boston College was also involved with the transfer of the Forecasting and Modeling Program from AFRL/RISA to the Air Force Weather Agency (AFWA), in addition to involvement with the BACIMO Conference, Cloud Optical Properties Tasks, Land Information System (LIS) and the NASA Snow Algorithm.

2.1.   FY08 Forecasting and Modeling Program

Boston College continued tracking and reporting status of FY07 Forecasting and Modeling (F&M) Program funds. FY 07 work is complete. All funds have been billed with the exception of $125K in NASA funds that are awaiting billing from University of Maryland. Also, the transfer of the Forecasting and Modeling Program from AFRL/RISA to the Air Force Weather Agency (AFWA), which provides background information and continuity as needed, was executed. AFWA was provided with information/documentation, as needed, from the previous year's efforts as well as schedule and planning info. AFWA continued to be consulted regarding research not yet delivered under prior year statements of work and helped AFWA formulate a plan to get all remaining work complete. Also, Boston College assisted AFWA in tracking progress on FY09 research tasks/expenditure of FY09 funds.

2.2.   Weather Research and Forecast Chemistry

Boston College helped capture lessons learned from the transfer of funding to NOAA for development of the Weather Research and Forecast Chemistry (WRF-Chem) in an effort to avoid what, in FY08, was an exceptionally difficult transfer. The mid-term review of WRF-Chem development by the National Oceanic and Atmospheric Administration (NOAA) Earth Systems Research Lab was attended. Currently, there is an effort to enhance the prediction of chemical and aerosol concentrations in support of military decision aids. Work related to this effort is being performed at the Earth Systems Research Laboratory (ESRL) in support of forest fire smoke cloud predictions. This work has the potential of helping predict aerosol concentrations in a dynamic environment and could be useful to the Air Force.

2.3.   Work with National Center for Atmospheric Research (NCAR)

Boston College was involved in the review process of the NCAR proposals for continued work on the following projects:

1.   Weather Research and Forecast (WRF) Model Improvement and Support
2.   NCAR Development Test Center
3.   WRF Data Assimilation

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4.   Joint Mesoscale Ensemble Development

NCAR presented the results of the tasks performed under the WRF model Improvement & Support Statement of Work (SOW), including Tropical Cyclone Bogusing Tasks; the WRF Model Data Assimilation Improvement & Support SOW; the Joint Mesoscale Ensemble Development SOW; and the Developmental Testbed Center (DTC) SOW. Carry-over tasks from the FY07 WRF Data Assimilation SOW were also presented. All proposals are ready for funding once the transfer of programs to AFWA is complete, and AFWA gets the necessary permission (Determination and Findings) to transfer funds. Boston College also participated in work being undertaken by NCAR in support of the AFWA Coupled Assimilation and Prediction System. The ultimate goal of this work is to assimilate weather observations into a single integrated model that predicts land surface, cloud, and "standard weather" properties. Work is continuing according to schedule.

2.4.   FY08 Cloud Optical Properties (COP) Tasks

Boston College reviewed the reported progress of FY08 Cloud Optical Property (COP) Tasks, and the project appears on track for an on-time delivery. FY09 work on this project will continue under the Systems Engineering, Management and Sustainment (SEMS) contract as part of the AFWA Coupled Assimilation and Prediction System. Boston College also was present at the Atmospheric and Environmental Research, Inc. Cloud Optical Properties delivery meeting and AFWA Coupled Assimilation and Prediction System technical interchange.

2.5.   Land Information System (LIS)

Boston College was present at the FY09 NASA Land Information System (LIS) and Snowdepth kickoff meetings and the FY08 LIS Technical Interchange Meetings. These meetings also addressed the possibility of integrating the Army Corps of Engineers Fast All-Season Soil Strength (FASST) land surface model into LIS. A delivery meeting for NASA FY08 LIS development tasks was attended by Boston College, which contributed to a Technical Interchange Meeting on the National Aeronautics and Space Administration (NASA) FY09 LIS tasks and the LIS WRF integration effort. FY09 work continues the FY08 effort to integrate the Community Radiative Transfer Model (CRTM) into LIS. The effort is continuing on schedule. Enhanced precipitation modeling is being developed and the ability to utilize the AFWA/NASA snow algorithm has been added.

3.   SPACE OBJECT SURVEILLANCE TECHNOLOGIES (SOST)

Boston College has continued work on generating realistic Bidirectional Reflectance Distribution Functions (BRDF) to model signals obtained from sun-illuminated resident space objects (RSO). The best ways of utilizing our simulation codes to produce meaningful results has been explored. Another area of interest is in space object identification (SOI), in which several methods have been employed.

3.1.   Time-domain Analysis Simulation for Advanced Tracking (TASAT) code

The Time-domain Analysis Simulation for Advanced Tracking (TASAT) code utilizes a Maxwell-Beard model to reproduce optical satellite signatures from 32 different satellite materials as a function of spectral band and solar and observer aspect angles. The parameters found in the TASAT material database can also be used with the Optical Signatures Code (OSC) to generate similar light curve data. The results from these two codes yield similar results, although OSC is less conducive to these types of calculation. Nonetheless, it is found that these models are unable to adequately simulate realistic signatures. This becomes evident when the spectral differences (differential in signals from two or more bands) are plotted against the total signal from all bands for a single satellite over many passes. These results show that there is little, if any, angular dependence in these spectral difference, as there is for light reflected from real surfaces.

3.2.   Magdalena Ridge Observatory (MRO) Data

Resolved images from an RSO viewed in many different spectral bands can also be used to understand BRDF's. Boston College has access to data in 16 bands for the International Space Station (ISS) from an experiment run at the Magdalena Ridge Observatory (MRO) in September 2007. By meticulously sampling various pixels from the images, one is able to track the observed signal from a solar panel in all spectral bands over the course of a single pass (in which the solar and observer aspect angles are changing). Signal from one solar panel of the ISS was tabulated for a period of over 100 secs (~10,000 images) of the ISS orbit. Also, various parts of the Zarya module can be sampled over a time period short enough that the aspect angles have not changed. Since Zarya is cylindrical in shape, this also gives us reflectance signal as a function of angle (and wavelength). The inherent angles are extracted by modeling the motion of the ISS with OSC and determining the geometry from the output files.

The ISS had been previously modeled using the OSC, and the simulation was employed to determine solar and observer elevation and azimuth angles for the ISS solar panel normal as a function of time. Several BRDF models were fit to the data to check the validity of the models. One interesting result of the analysis shows the inability of the standard models to reproduce reflections from multiple interfaces on a single surface. For the first time since acquiring the MRO data, extensive tabulation of all of the data from all visible satellites (generally, non-resolved) was also accomplished. Future plans for the total signal from each object in the 16 spectral bands of our imager involve a procedure for extracting the most satellite information possible. A total of 24 satellite passes were sampled. OSC was used to generate range files for each pass.

3.3.   Neural Network Techniques for SOI

Boston College has started a collaboration with Val Bykovsky at AFRL on applying neural network techniques to light curves from unresolved space objects for the purpose of SOI. Since this is initially just a proof-of-principle examination, simulated data is used to train the neural net engine. Simulated light curves for various classes of satellites (satellite bus-type, solar panel configuration, stabilization processes, etc.)

executing multiple passes were generated and made available to Dr. Bykovsky. By training a neural network with examples of light curves from a selection of satellites, the network learns to identify unknown satellites from their light curves. In all, roughly ten satellites were simulated, with the plans for more, once the initial results are seen. Active satellites are stabilized by a variety of methods which allow the solar panels to constantly face the sun and have antennae zenith-pointing. In addition, inactive satellites are modeled as tumbling (e.g., rocket bodies) or drifting (e.g., deactivated payloads).

The first test will be to determine if the engine is able to classify light curves from unknown satellites and identify the probability of the satellite's identity to high accuracy. An attempt was being made to find the saturation point for how many light curves are needed to effectively train the system. The next test will involve a subset of these satellites simulated with different sets of materials. The temporal signatures of these satellites are similar; the test will be to see if the spectral information contained in the simulated data helps to separate these objects in feature space. In addition, the orbits of these satellites have been modified to give reasonably realistic passes.

OSC was also used to simulate data from a set of generic satellite bus-types with a variety of spacecraft materials used for the training and testing of the neural network. For each satellite, 56 light curves from 56 slightly different passes of the satellite are generated. Each file contains signal in 16 different bands stretching from $414 - 846$ nm, along with information about the orbits themselves. Accuracy in identification has been lacking, even in the most basic tests. In addition, the results themselves seem anomalous. New methods have been tried, including, 1) using a significantly different set of surface materials for each satellite; 2) using fewer, pre-selected light curves for testing; and 3) adding another field to the data files which incorporates spectral and temporal information in a single column of numbers and using that for training and testing. The result of these changes is fewer anomalous-appearing data sets and better satellite identification. This has been done for three satellites and started for a set of four. A system of scoring the "goodness" for each result has been established in order to quantify progress.

In conjunction with the neural network project, more efficient code has been written to run multiple OSC simulations in less time. Data from many passes of the same satellite is useful for SOI, whether it is real data or simulated. Work has started on finding ways to automatically generate multiple runs of the TASAT software. Eventually, it is hoped that "smart" runs of the software can be accomplished; that is, given real data from a satellite and choosing some set of initial conditions for a simulation, a feedback loop can be implemented that allows some code to decide how to change the parameters of the simulation to best match the data.

3.4. Collaboration with Air Force Maui Optical and Supercomputing (AMOS)

Boston College has also started working on the analysis of data taken at the Air Force Maui Optical and Supercomputing (AMOS) site using the Broadband Array Spectrograph System (BASS). Several satellites were observed and the data analyzed. Questions about the data were resolved using OSC to determine solar phase angle (SPA), range, time of penumbra entrance/exit and to generate the probable attitude of the objects during the course of their passes, In this way, the results of the data could be validated.

This peripheral analysis provided enough information to question some of the results, and after further investigation, sources of error were recognized, thus leading to an improved model. Before this error was recognized, an exhaustive examination of the calibration procedure was performed, including consideration of the many calibration stars used. More data has been requested. The choice of which satellites to observe is predicated on previous results and issues raised by their analysis. OSC simulations of the requested satellites have been started to use as guides in analyzing the data. Other sources of data are also being explored.

3.5. Short Wave Infrared (SWIR) Detector Selection

Boston College has also started getting involved with the researching of short-wave infrared (SWIR) sensors for possible integration into the AFRL satellite-tracking system, or perhaps into the optical chain of other telescopes. The SWIR has recently been shown to be useful as a diagnostic tool in remotely studying the ageing of solar panels.

4. HYPERSPECTRAL IMAGING (HSI)

Boston College researchers have also been involved with three projects in AFRL/RVBYH: the TacSat-3 program, the image processing software FLAASH, and the radiation transport equation solver MODTRAN™.

4.1. TacSat-3 Program

The TacSat-3 program produced a satellite-based hyperspectral sensor, which was launched aboard a Minotaur rocket on May 19, 2009, and Boston College was responsible for writing most of the software to process raw data as downloaded from the satellite. As the satellite launch neared, the focus was to finalize the software tools and package them together in an automated processing chain that produces the final product: image data suitable for analysis by scientists. This culminated in a complete test of the data processing chain, including the transfer of the raw data from a remote site (simulating the download of data from the satellite) and the transformation of the raw data into usable images for scientific analysis. Now that the mission is in progress, the initial software package has been supplemented with updates and bug-fixes as data has been downloaded from the satellite. Since this is a research satellite, the Air Force expects to exercise the satellite to discover its limits, thus requiring additional software modifications to be performed as these experiments are conducted.

4.2. FLAASH Code Image Processing Software

The Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) code is image processing software designed to remove the effects of the atmosphere from airborne or satellite imagery. Boston College has been responsible for improvements in this code related to the processing of very large images. These images are so large that different atmospheric characteristics separated by the large distances bounded by the image can affect the accuracy of the results. Work in this area has been related to

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verification and acceptance testing of this new feature of the code. Because of the multi-gigabyte images generated by the TacSat-3 sensor, FLAASH had to be modified to be able to handle these huge images. While much work was performed on FLAASH prior to the mission, there is no substitute for real data. The image data from the satellite was significantly different compared to the simulated data, requiring some of the algorithms to be tweaked for optimal performance. It is anticipated that additional small modifications may be required, but no large scale FLAASH work is envisioned for the upcoming quarter.

4.3. MODTRAN®

An effort related to the MODerate Resolution Atmospheric TRANsmission (MODTRAN®) radiation transport equation solver, a computer program that calculates radiative transfer in the atmosphere, has been related to configuration control. Previously, the source code for MODTRAN® has been maintained in an informal manner by another contractor. Boston College had been tasked with designing a system to formalize the software development process of MODTRAN® using products consistent with commercial best-practices. The work related to MODTRAN® was divided into two segments:

1) An effort related to the TacSat-3 program
2) A separate effort related to the configuration control system for future development of the software

MODTRAN® is needed to produce data that FLAASH then uses to process the image. Some anomalous pixels were observed in some FLAASH images, and it was determined that MODTRAN® was the cause. Several detailed studies on the causes of the anomalies were performed, and some of these studies are still in progress. This process is applicable to both government and contractors; all persons who have a stake in the MODTRAN® development will be required to conform to the software development practices which were created by Boston College. This work yielded a document describing the process and a proof-of-concept system including configuration control using Subversion (http://subversion.tigris.org), and an issue tracking database using Trac (http://trac.edgewall.org). It is expected that early in the next year, the other contractors involved in the project will supply their missing data, and that the government and other stakeholders will give the system their final approval.

5. SOLAR MASS EJECTION IMAGER (SMEI)

The Solar Mass Ejection Imager (SMEI) graphical user interface (GUI) analysis tool was ported to a Windows environment and delivered to AFWA. Travel was arranged to AFWA for installation and demonstration. Feedback from AFWA personnel was immediate and suggestions for an update were noted. The CBZODY 7 software package was employed to provide fits to the SMEI data.

Analysis of the SMEI data has led to a journal article entitled, "Measurements of the Gegenschein brightness from the Solar Mass Ejection Imager (SMEI)," which was published in *Icarus*.

The following changes were made subsequent to their suggestions for the next software delivery:

1. A crosshair is provided for the position of the Sun;
2. The help button opens two windows. The first is a description of the basic use of the GUI. The second window contains a flow chart illustrating the steps for measuring a heliospheric disturbance;
3. A keyword was added at start up to optionally blank Camera 3 data; and
4. A second keyword was added to clip the high and low scaled levels in the image frames to zero to make a less complicated display. This has the effect of blanking the particle hit/auroral zones. The blanking occurs at ±3 display levels by default, but this can be adjusted by the user by setting it at the keyword level.

Measurements were completed for all 40 launches that were possibly observed by SMEI. About half of these had diffuse observations, indicative of a launch. The other half were slowly moving point sources, most likely not related to a launch. Along with the attitude measurements, movies and FITS images were generated of the related frames. A select few of the plume observations are now undergoing further analysis including time evolution of the plumes' flux. One of the first steps in the SMEI zodiacal analysis is to use SMEI to refine and validate the current visible light predictions of the Celestial Background Scene Descriptor Zodiacal Emission (CBZODY) model. The most efficient way to do this is fit the model to the zodiacal variations observed at the north and south ecliptic poles to the SMEI data. These variations are caused as the Earth passes through the tilted cloud. The proposed work will use high resolution zodiacal light maps from six years of SMEI's bi-monthly calibration observations. These maps will be data filtered to remove observational contaminants (moon, aurora, particle contamination, etc), systematic camera artifacts (glare, CCD variations) and the celestial background (stars and galaxy), thus providing the best photometric observations possible. Currently, 29 of these maps have been produced.

5.1. Celestial Background Scene Descriptor Zodiacal Emission (CBZODY-7)

Once the SMEI filtered maps are produced, the input parameters to the CBZODY code will provide a best fit to the SMEI data. CBZODY maps will be generated for each of SMEI's calibration periods. The physical parameters of the dust clouds (dust scattering properties, scattering function, cloud size and extent, inclination, etc) will be adjusted to provide a "best fit" to the observations in a least square sense. Once this best fit is obtained, the residuals will be examined for periodic trends that may be indicative of other dust cloud properties and variations that are not modeled in the current version of CBZODY. It was decided to use the current version (7) of the CBZODY software rather than the version used (6) for the gegenschein analysis. Since the SMEI data is being processed for the whole sky, the current version has a more accurate representation of the zodiacal bands. A new scaling factor had to be determined to bring the version 7 model

output (in MJy sr^{-1}) into the native SMEI flux units (unscaled analog-to-digital units, ADUs). This factor was empirically measured as 147 ± 2 ADUs/ MJy sr^{-1}.

Boston College recognized that in the list of 40 satellite launches, SMEI may have seen fuel dumps as well as second stage ignitions. Usually the fuel dumps occur shortly after launch whereas the second stage ignitions can occur as late as 5-7 days after the initial launch. Since only three days of the SMEI data were examined post-launch, it is possible that most of the original identifications were fuel dumps after the satellites reached their initial orbits. To determine if SMEI did observe some late second stage burns, the data were re-examined for up to seven days post-launch. Three more observations were found for candidate fuel dumps/second stage burns from the list of 40. Confirmation of these as second stage burns is underway. With the current limitations of the data, the overall fluctuations seen at the poles were still apparent. Since the data from Cameras 1 and 3 showed the larger discontinuities, a double sine curve was fit using only Camera 2 data. These plots were used to match and modify the CBZODY 7 model. This effort is continuing. Also, a second approach was employed in an effort to mitigate the discontinuities. Focusing solely on the poles themselves necessarily relies on data from all three SMEI cameras. However, Camera 2 continuously observes portions of the sky, near the poles (approximately 75°), at a constant solar elongation. Using a patch from this section of the sky and matching to the CBZODY 7 model might prove more useful than using the poles. One complication in this method is that the star field now varies during the year, whereas this was a constant factor (and therefore easily removed) at the poles. Presently, the Boston College researcher is in the process of obtaining star-subtracted SMEI data, which should alleviate this problem. A second list of 25 Ariane launches was examined to see if SMEI observed any fuel dumps/second stage burns. Seven candidates were observed and measured in this list. Along with this list four new serendipitous observations/measurements were made with the SMEI data, including an apparent swarm of debris.

6. DIFFUSE INFRARED BACKGROUND EXPERIMENT (DIRBE)

Corrections to the cold epoch data of 2100 slowly varying stars have been completed for four Diffuse Infrared Background Experiment (DIRBE) bands. The flux and ancillary files, required for computing the corrections, have been delivered to AFRL for analysis. In addition, corrections are being applied to warm epoch measurements of these 2100 stars. To date, approximately one third of the first band and one quarter of the second have been completed. Observations that failed to have converging corrections were culled on the list.

7. MSX DATA MINING

Analysis of the Midcourse Space Experiment (MSX) mirror-scan radiometer data continued. IDL routines have been developed to assist in the effort.

Software for the processing of the RSO candidate observations for the mirror-scan radiometer data has been extensively revised, tested, and applied. The code has been optimized for handling targeted RSOs, in which the object is observed in nearly every raster scan in a data collection event (DCE), and also serendipitous observations in which

an RSO is by happenstance observed in a prolonged sequence of raster scans. The prior version of the image processing code for the RSOs was optimized for mirror-fixed data in which a given target will typically cross the detector stack once due to spacecraft slewing, proper motion and parallactic effects. For the mirror-scan data, an RSO will typically cross the detector stack multiple times, with brief intervals, due mainly to the mirror-scan motion itself. The processing code has been modified to effectively accommodate this difference in observational characteristics.

The set of early midcourse (EM) DCE RSO candidates has been reprocessed with the revised code, candidate images have been visually inspected for the presence of the RSOs, and the final flux files have been regenerated. The mirror-scan Earth limb (EL) events have also been reprocessed, and the image inspection is about two-thirds complete. Fluxes of the positive RSO observations have been calculated, and final flux files with ancillary information have been generated. IDL routines for position-tagging pixels in the MSX Space-Based Visible (SBV) image arrays have been developed. IDL routines for reprocessing MSX EL events for time-series clutter analysis have been developed, including routines to convert time to Earth coordinates of the corresponding tangent points, and calculation of the power spectral density from the resulting radiance/distance relation.

8.   MIPSGAL DATA ANALYSIS

Analysis of the set of evolved stars with circumstellar shells identified in the 24 micron Multiband Imaging Photometer for Spitzer/Galactic Survey (MIPSGAL I and MIPSGAL II) data products has been continued. MIPSGAL is a galactic survey using the Multiband Imaging Photometer for the Spitzer/Galactic Survey Space Telescope at the Space Infrared Telescope Facility (SIRTF). In particular the morphology of the objects has been studied in an effort to devise a physically meaningful classification scheme, and the presence or absence of the objects in other Spitzer wavelength bands has been examined for the same objective. A catalog of these objects has been generated, and a paper presenting the results has been prepared and is being finalized for submission.

9.   SPACE SITUATIONAL AWARENESS (SSA)

Boston College supported Space Situational Awarness (SSA) with data management of the AFRL HyCAS sensor and involvement with the ARTEMIS data.

9.1.   Calibration Laboratory Support

Boston College continues to support software development, data processing and data management for the AFRL Hyperspectral Calibration laboratory. Calibration coefficients and instrumental profiles were delivered to the National Air and Space Intelligence Center (NASIC) for the Hyperspectral Collection and Analysis System (HyCAS) sensor. These data are a culmination of the laboratory and processing tasks. In addition, bad pixel assessments and a lessons learned document were delivered to AFRL. The data was re-examined. The idea was to check sensor data collected in benign conditions to assess if pixels show random anomalous amplitudes or "flickers". The

analysis was initiated, but was put on hold due to the launch of the Advanced Responsive Tactically Effective Military Imaging Spectrometer (ARTEMIS) sensor. Work continues to develop calibrations for the internal laboratory instruments including the ASD spectrometer and radiometric monitors such as the silicon and InGaAs detectors.

Codes were developed to both calibrate hyperspectral instruments as well as instruments and lamps used in the calibration procedures. Because these codes were developed while the calibration measurements were being taken and NASIC required a quick turn-around, the ad-hoc library was not fully automated or documented. Boston College, in conjunction with AFRL, decided to unify the library by using one coding language on one platform to process calibration data and to develop robust documentation. All data are to be processed on a UNIX system using the MATLAB® language and all binary outputs will be written using big-endian encoding. Since both AFRL and Boston College will be using the code library to process the calibration data, the documentation must be thorough and somewhat user friendly. The approach has been to create sub-functions that can be used by multiple calibration activities. A total of 40 sub-functions are currently available. Twelve main functions are used to calibrate the hyperspectral imaging (HSI), Analog Spectral Devices (ASD) and transfer radiometer data. Utilities to create database of measurements, to fix any header errors, and to read and write ENVI® style headers were also developed. Currently, MATLAB® functions to calibrate hyperspectral instruments are the most mature. ASD processing functions have been developed, however, the method of ASD data collection is expected to be upgraded and data are currently unavailable for testing. Boston College has delivered these preliminary functions to AFRL for testing and will assist AFRL in learning how to apply these codes to existing calibration data.

9.2. Calibration of the ARCHER Imaging System

The ad-hoc processing codes used to calibrate the HyCAS sensor were written in both IDL and MATLAB® programming languages and were run on both Windows and UNIX platforms. These functions represent a significant upgrade to the codes used to calibrate the Airborne Real-Time Cueing Hyperspectral Enhanced Reconnaissance (ARCHER) imaging system last year. The library includes utilities to read, process (average and/or bin) and write data, to build a database of measurements, to calculate calibration parameters such as instrumental profile and calibration coefficients. Other routines assess sensor linearity and bad pixels.

9.3. ARTEMIS Support

Expertise concerning data formats, distribution requirements and data processing requirements has been provided to AFRL from Boston College researchers. In addition, Boston College is working with MIT Lincoln Laboratory to extend the MODTRAN® modeling effort which was published by one of our researchers in 2006. Boston College is also collaborating with Dr. Vittala K. Shettigara of the Australian Defence Science and Technology Organization (DSTO) on a target detection study using ARTEMIS data. Dr. Shettigara was been a visiting scientist at AFRL for six months. During the first quarter, procedures were established to embed synthetic targets in the scene and to assess target

detection performance. A preliminary report was presented to AFRL. The ARTEMIS sensor was successfully launched on May 19, 2009 from the Wallops Island Flight Facility. One of our researchers attended the first launch attempt on May 5, however, the weather prevented a successful launch. Boston College has participated in data processing and image analysis during the early operations and calibration phases by providing expertise in focus analysis, spectral calibration assessment and flat-field assessment.

10.   STELLAR PHOTOMETRY

Stellar photometric calibrations were made using MSX and HIPPARCOS Satellite and the Hubble Telescope data. Generation of synthetic spectra spanning the near UV wavelengths has been started. A new visible-to-IR calibration standard has been investigated to compare to that from Vega, which has been seen recently to vary significantly over time.

The newly introduced calibration depends instead on the star 109 Vir from 0.3-0.9 μm (a stable A0 V star which had been compared to a calibrated blackbody in the 1970s) and on the A1V star Sirius (α CMa) from 0.9 -35.0 microns. To set the absolute reference flux distribution above 0.9 μm, the direct calibration of Sirius in the 12, 15, 21 μm bands of MSX from an earlier publication is utilized, as well as the Hubble Space Telescope's Near Infrared Camera and Multi-Object Spectrometer (NICMOS) calibrated observations of A type stars from 0.8-2.5 μm and the Infrared Space Observatory (ISO) Short-Wave Spectrometer (SWS) 2.4-9.5 μm spectrum of Sirius. The shape of the resulting calibration reference spectrum was further verified using the solar analog method: Ratios of a pieced-together A-star spectrum's computer-integrated flux over various wavelength bands were taken with respect to the corresponding integrated fluxes of the Sun (using a commonly accepted semi-empirical representation of the solar absolute spectrum based on many absolutely calibrated measurements as well as theoretical modeling). This was compared to published average ratios actually measured in various bands comparing A-stars to solar analog stars.

The relative behavior of these 'model' A-star and Solar spectra and that of the actual measured A-type and solar type stars agreed to within 0.25 percent. Therefore, because of the impressive mutual agreement, confidence is raised in the new zero-magnitude spectral reference introduced in the submitted paper, as well as in the solar semi-empirical model used for comparison and the observational spectral photometry on actual A and solar analog stars. Therefore, the resulting calibration neatly incorporates all the non-Vega absolute calibration data available and can be expected to become the new standard for use in the field.

Work has started on building a set of synthetic spectra representing other well know stars (those included in the Cohen-Walker-Witteborn (CWW) secondary list of stellar standards) calibrated relative to this primary standard. These will span the 0.3-35 μm range and represent stars scattered over the sky which can be observed at will by instruments for convenient calibration and monitoring. The conversion of a collection of 600 stellar templates to a new calibration has continued.

A journal article detailing a new visible-to-infrared stellar calibration reference standard was written and cleared for submission to *Astronomical Journal*. The article is

entitled, "Spectral Irradiance Calibration in the Infrared. XVII. Zero Magnitude Broadband Flux Reference for Visible to Near-IR Photometry". The new standard is introduced because Vega (α Lyr), the primary calibration star previously used for stellar calibration by researchers in both the visible and infrared, was found to vary significantly over time and have a poorly characterized spectral energy distribution.

11.   CONCLUSIONS

During the period September 2008 through September 2009, we conducted innovative research in areas relating to development and demonstration of new technologies to predict atmospheric effects on sensor performance for acquisition, mission planning and employment of the Air Force's current and next generation electro-optical (EO) systems. Emphasis includes space-, air-, and ground-based EO systems, laser systems including the ABL, surveillance and lidar and radar remote sensing technologies.

In the Turbulence effort, Boston College coordinated with AER on FY08 Cloud Optical Propertics, and with the NCAR on assimilation of the Weather Research and Forecast (WRF) data. Boston College was also involved with the transfer of the Forecasting and Modeling Program from AFRL/RISA to AFWA, in addition to involvement with the BACIMO Conference, Cloud Optical Properties Tasks, LIS and the NASA Snow Algorithm.

In the SOST effort, Boston College researchers worked to generate empirical models for BRDF's, began a project in which neural network techniques were used to determine SOI and conducted research into the effectiveness of using SWIR to determine ageing of spacecraft materials. Analysis of BASS data from AMOS was also commenced.

Boston College also continued to support the Hyperspectral Imaging effort at AFRL by writing software to package image data downloaded from the TacSat-3 satellite and improving the FLAASH code used for image processing. Validation and verification of a new version of the MODTRAN™ radiation transport code has also been addressed.

The SMEI graphical user interface was ported to a Windows environment and delivered to AFWA. Measurements were completed for possible launches observed by SMEI with the assistance of the CBZODY-7 model.

Boston College was in part responsible for corrections to the cold epoch data of 2100 slowly varying stars have been completed for four DIRBE bands.

Analysis of the Midcourse Space Experiment (MSX) mirror-scan radiometer data continued, including the revision, testing, and application of new IDL routines to assist in the effort.

Boston College continued to support the MIPSGAL data analysis in an effort to devise a physically meaningful classification scheme, and the presence or absence of the objects in other Spitzer wavelength bands has been examined for the same objective.

Boston College provided ARTEMIS and Calibration Laboratory support, including calibration of the ARCHER system in the Space Situational Awareness effort. Codes were developed to both calibrate hyperspectral instruments, as well as other instruments and lamps.

In the Stellar Photometry effort, calibrations were made using MSX and Hubble Telescope data, and a new visible-to-IR calibration standard has been investigated to compare to that from Vega, which has been seen recently to vary significantly over time.

List of Symbols, Abbreviations, and Acronyms

ABL	Airborne Laser
AER	Atmospheric and Environmental Research, Inc.
AFRL	Air Force Research Laboratory
AFWA	Air Force Weather Agency
AMOS	Air Force Maui Optical and Supercomputing
ARCHER	Airborne Real-Time Cueing Hyperspectral Enhanced Reconnaissance
ARTEMIS	Advanced Responsive Tactically Effective Military Imaging Spectrometer
ASD	Analog Spectral Devices
BACIMO	Battlespace Atmospherics and Cloud Impacts on Military Operations
BC/ISR	Boston College/Institute of Scientific Research
BRDF	Bidirectional Reflection Distribution Function
BASS	Broadband Array Spectrograph System
CBZODY	Celestial Background Scene Descriptor Zodiacal Emission Model
CCD	Charge Coupled Device
COP	Cloud Optical Properties
CRTM	Community Radiative Transfer Model
CWW	Cohen-Walker-Witteborn
DCE	Data collection event
DIRBE	Diffuse Infrared Background Experiment
DoD	Department of Defense
DSTO	Defence Science and Technology Organization
DTC	Developmental Testbed Center
EL	Earth limb
EM	Early Midcourse
EO	Electro-optical
ESRL	Earth Systems Research Laboratory
FASST	Fast All-Season Soil Strength
F&M	Forecasting and Modeling
FLAASH	Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes
GUI	Graphical User Interface
HSI	Hyperspectral Imaging
HyCAS	Hyperspectral Collection and Analysis System
IR	Infrared
ISO	Infrared Space Observatory
ISS	International Space Station
LIS	Land Information System
MIPSGAL	Multiband Imaging Photometer for Spitzer /Galactic Survey
MODTRAN®	Moderate Resolution Atmospheric Transmission
MRO	Magdalena Ridge Observatory
MSX	Midcourse Space Experiment
NASA	National Aeronautics and Space Administration
NASIC	National Air and Space Intelligence Center
NCAR	National Center for Atmospheric Research
NICMOS	Near Infrared Camera and Multi-Object Spectrometer

NISOI	Non-Imaging Space Object Identification
NOAA	National Oceanic and Atmospheric Administration
OSC	Optical Signatures Code
RSO	Resident Space Object
SBV	Space-Based Visible
SEMS	Systems Engineering, Management
SIRTF	Space Infrared Telescope Facility
SMEI	Solar Mass Ejection Imager
SOI	Space Object Identification
SOST	Space Objects Surveillance Technologies
SOW	Statement of Work
SPA	Solar Phase Angle
SSA	Space Situational Awareness
SWIR	Short-Wave Infrared
SWS	Short-Wave Spectrometer
TASAT	Time-domain Analysis Simulation for Advanced Tracking
UV	Ultraviolet
WRF	Weather Research and Forecast